NATIONAL RADIO ASTRONOMY OBSERVATORY

VLA ELECTRONICS MEMORANDUM NO. 9

March 12, 1968

STATUS OF IF TRANSMISSION SYSTEM

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General System Design

The ITT Federal Laboratories system design study recommended a cable system for transmission of the VLA IF signals. A microwave-link system had been rejected early in the study, and it was decided in March, 1967 that a short, internal study of a microwave link system would be made.

The results of this study are documented in VLA Electronics Memorandum No. 2, "Consideration of a Microwave Link IF Transmission System." The advantages of the microwave link system are:

1) Approximately $500 K lower construction cost.
2) Greater flexibility with respect to location of observing stations.
3) Ease of expansion to baselines longer than the planned 21 km.
4) Potentially greater reliability because of the lack of a series repeater system.

The disadvantages are:

1) A frequency allocation of 1800 MHz bandwidth is required.
2) There is a danger of interference of the link into the receiving array and of external interference into the link.
3) The array antennas tend to block the link and the link towers tend to block the array. This problem is especially acute at the Wye center.

It would be very difficult to be certain that problems 2) and 3) were solved before the entire array was constructed. On the other hand, the cable transmission system can be debugged in a prototype stage and then will operate with little interaction with the site environment or other portions of the array. For this reason, the cable system was chosen for detailed design and prototyping.

Two other types of IF transmission systems have been briefly considered. These are an optical transmission system and TE_{01} circular waveguide transmission. On both cases there are technical problems which, so far, have prevented commercial application. The reliability of these systems is unknown and it does not appear prudent to use a new and unproven transmission method in a complex instrument such as the VLA.

Cable System Design

The design of a cable IF transmission system requires the selection of cable type, frequency band, degree of multiplexing, and a modulation system. These choices must be made considering cost, reliability, repeater noise, intermodulation noise, cross-talk, phase non-linearity, and amplitude distortion.

Studies of these factors are presented in the ITT final report and the following internal reports:

VLA Electronics Memo No. 5 — "Comparison of Modulation Systems for Transmission through Dispersive Cables"

VLA Electronics Memo No. 6 — "Prototype IF Transmission System"

VLA Electronics Memo No. 7 — "Equalization and Signal-to-Noise Problems in the IF Transmission System".

The following conclusions may be reached from these reports:

1) The lowest cost system will utilize either 7/8" or 1 5/8" coaxial cable with transmission of 4 to 12 IF signals per cable in an octave band beginning at 300 to 1000 MHz. The above bounds define a broad minima of cost and the optimization within these bounds can be governed by other factors.

2) The system selected for prototyping will utilize 1 5/8" cable, 12 signals per cable, and a 1000 to 2000 MHz frequency band. This choice makes equalization less cirtical (since a small percentage bandwidth is used), contains a minimum number of cables, and utilizes 1000 to 2000 MHz transistor amplifiers which are readily available.

3) The requirements defined by noise, phase linearity, cross-talk, and amplitude distortion are quite attainable. A repeater gain of $\sim$ 40 dB and repeater spacing of 800 meters are dictated.

4) A double side-band modulation system has the simplest terminal equipment and the highest tolerance to cable dispersion and attenuation variation with frequency. However, a single side-band system requires only 0.6 as much cable and appears to be quite feasible. A final decision will be made after prototype repeaters and modulators have been evaluated.

Status of Prototype System

A prototype IF transmission system is described in VLA Electronics Memorandum No. 6. A block diagram of the system is shown in Figures 1 and 2.

The construction of the prototype system was begun in January, 1968 (except for construction of cable equalizers which began a few months earlier). The first task has been the evaluation of critical components of the system. The initial results of this evaluation have been quite good and there is little doubt that the system is feasible. A brief description of the status of the critical components is as follows:

Cable

A request for quotation on 1 5/8" coaxial cable was sent to all potential manufacturers on December 22, 1967. The quotations and electrical performance of various manufacturers' cable are presently being evaluated.

An unknown parameter has been the dispersion (variation of propagation velocity with frequency) of 1 5/8" cable in the 1000 to 2000 MHz range. The dispersion affects the phase non-linearity of the transmission. Little data or theory is available concerning dispersion.

The results of the measurements of one manufacturer's 1 5/8" cable are shown in Figure 3. The maximum dispersion of this cable is 1.4 ns for 21 km and 50 MHz single-sideband transmission. This amount of dispersion would have little effect upon the VLA system and is easily compensated.

The above cable has a longitudinal dielectric configuration whereas other manufacturers of cable utilize a helical dielectric. On the basis of a theoretical paper and a manufacturer's measurement of helical dielectric cable, it appears that the helical dielectric gives a factor of 20 greater dispersion and should not be used. We are obtaining 1000' of helical dielectric cable for our own evaluation.

Repeater Amplifiers

There are five manufacturers who have developed 1000 to 2000 MHz transistor amplifiers. Several units of the most experienced manufacturer of these amplifiers have been tested and appear to be quite suitable for use in the system. The phase and amplitude response of one of these amplifiers is shown in Figure 4.

Specifications for the repeater amplifiers are presently being written and a request for quotation will be sent to all potential manufacturers during March, 1968.

Equalizer

The attenuation of all coaxial cables varies approximately as $f^{1/2}$. This variation must be compensated in order to prevent amplitude distortion of the transmitted signals.

The design of cable equalizers in the video frequency range is readily available in the technical literature. However, no references have been found for attenuation equalizers in the UHF or microwave range where complex lumped-circuit element networks are not feasible.

A trial-and-error computer design of a transmission-line type equalizer was begun in June, 1967. The network that has evolved is shown in Figure 5. A cascade of two of these networks should equalize the 13 dB slope of 800 meters of 1 5/8" between 1000 and 2000 MHz to within 0.5 dB.

Several equalizers similar to the one shown in Figure 5 have been constructed and the performance is very close to theoretical predictions. Work is presently being done to match the equalizer to 50 ohm transmission line, and tests of the equalizer-cable cascade will begin quite soon.

Single-Sideband Filters

The simplest method of single-sideband modulation and demodulation involves the use of a sharp cutoff filter to remove the unwanted sideband. The required sharpness of the filter depends on the ratio of highest to lowest frequencies in the modulating signal. An IF band of 8 to 50 MHz has been chosen as a compromise which allows a feasible sideband filter and yet does not lose too much bandwidth (i.e., the band between 0 and 8 MHz).

A sharp cutoff filter tends to have a non-linear phase response in the pass band. The non-linear phase will not be detrimental to the system if it is not too severe and can be matched from one IF signal to another.

The phase and amplitude response of several bandpass filters has been measured. The results indicate that the phase non-linearity will not be a serious problem but none of the filters that have been evaluated have sufficient amplitude cutoff to give a minimum of 25 dB rejection of the unwanted sideband. The response of the best filter evaluated so far is shown in Figure 6.

Discussions with filter manufacturers have led us to believe that the desired filter is feasible. Specifications and a request for quotation were sent to all potential suppliers on February 12, 1968; replies have not yet been received.

Fugure Program

The work on testing of critical components described in the previous section is part of the development of a prototype IF transmission link. This link needs to be long enough so that any troublesome effects in the 21 km system can be detected in the prototype link. Our present plans are to construct and test a 4.8 km link (6 repeaters) by January, 1969.

Two theoretical studies will be the subject of future internal reports. The first report will describe the degradation of signal-to-noise as caused by phase non-linearity and amplitude variation. A method of pulse testing the system response will all be described. This work has been done in rough form and, in fact, has been used to set the phase and amplitude error budgets in VLA Electronics Memorandum No. 6.

The second theoretical study will relate the system reliability (as defined in Chapter 19 of the VLA Proposal — essentially fraction of available Fourier components) to the failure rate and repair times of repeaters. This study will lead to recommendations concerning redundancies and fault correction techniques in the final system.

After the prototype link has been tested, final, manufacturing prototypes of all elements of the system will be developed. These prototypes will correct for technical deficiencies in the first stage prototype and will contain the packaging and monitor facilities desired in the final system.

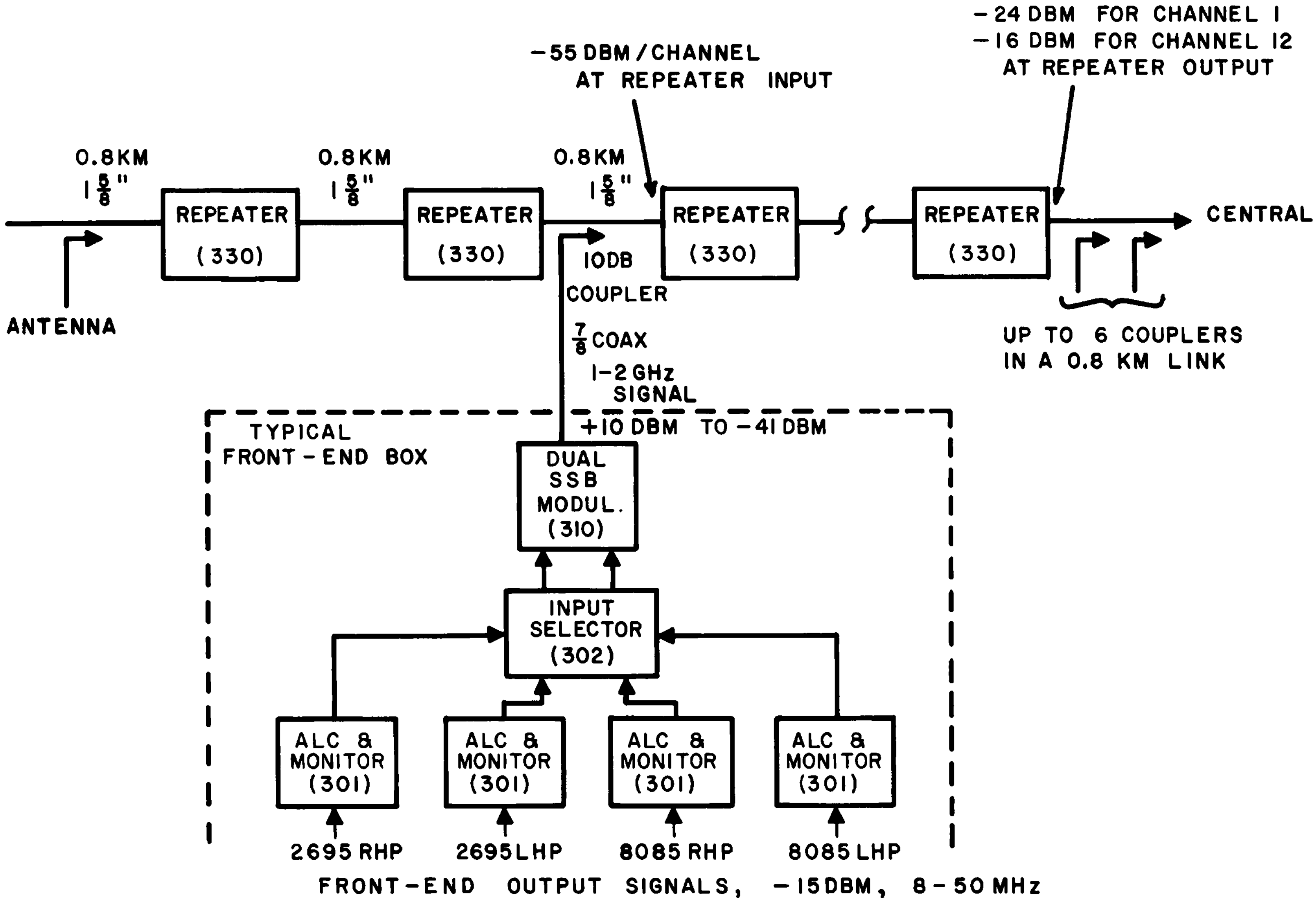


Figure 1 — Block diagram of front-end box and transmission line portion of prototype IF transmission system. Two of the four possible input signals (2695 or 8085 MHz, right-hand or left-hard circular polarization) are transmitted as upper and lower sidebands of a carrier in the 1096 to 1904 MHz range. Construction of a 5 km segment of this system is planned during the next 6 months.

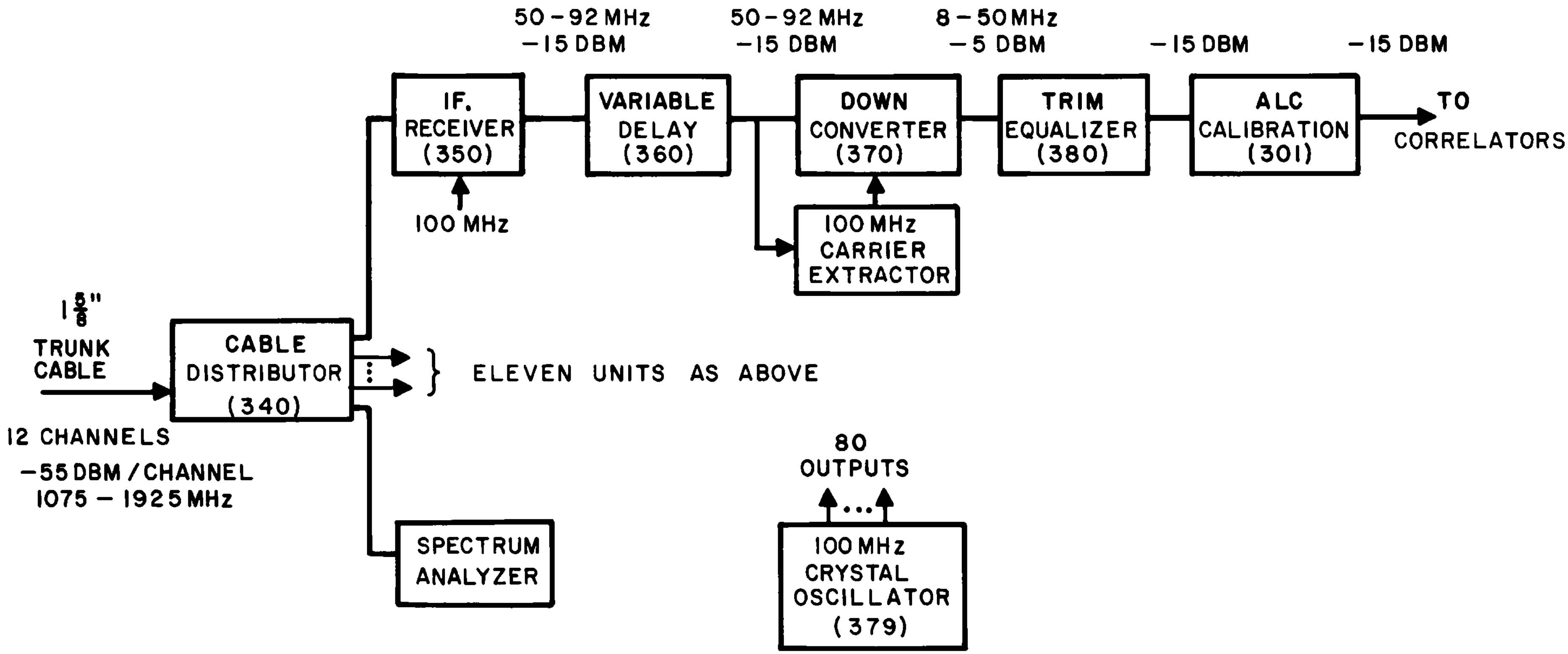


Figure 2 — Block diagram of central control room portion of the prototype IF transmission system. The IF receiver translates one IF signal from the 1000-2000 MHz region down to the frequency of the variable delay line. More detailed block diagrams are given in VLA Electronics Memorandum No. 6.

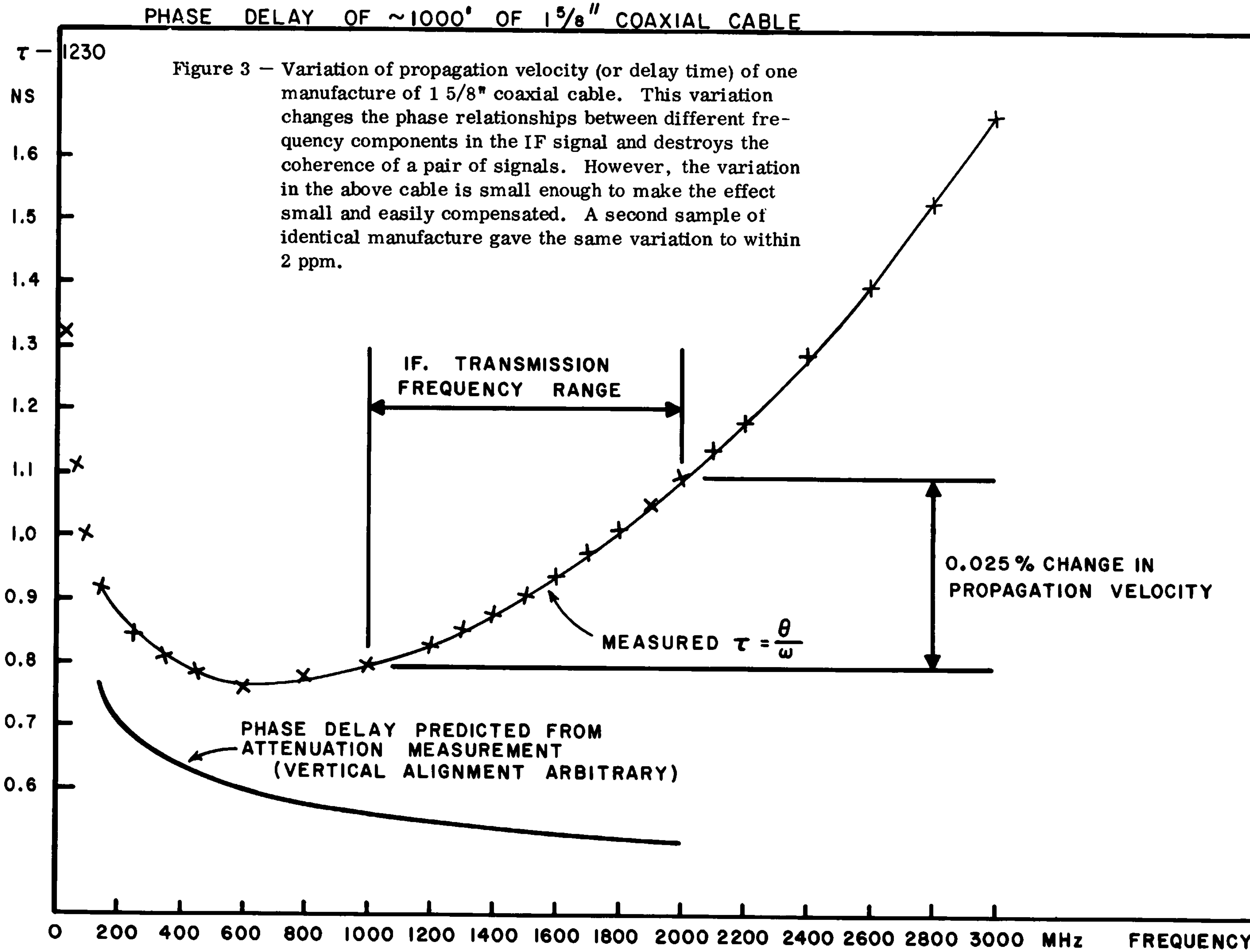
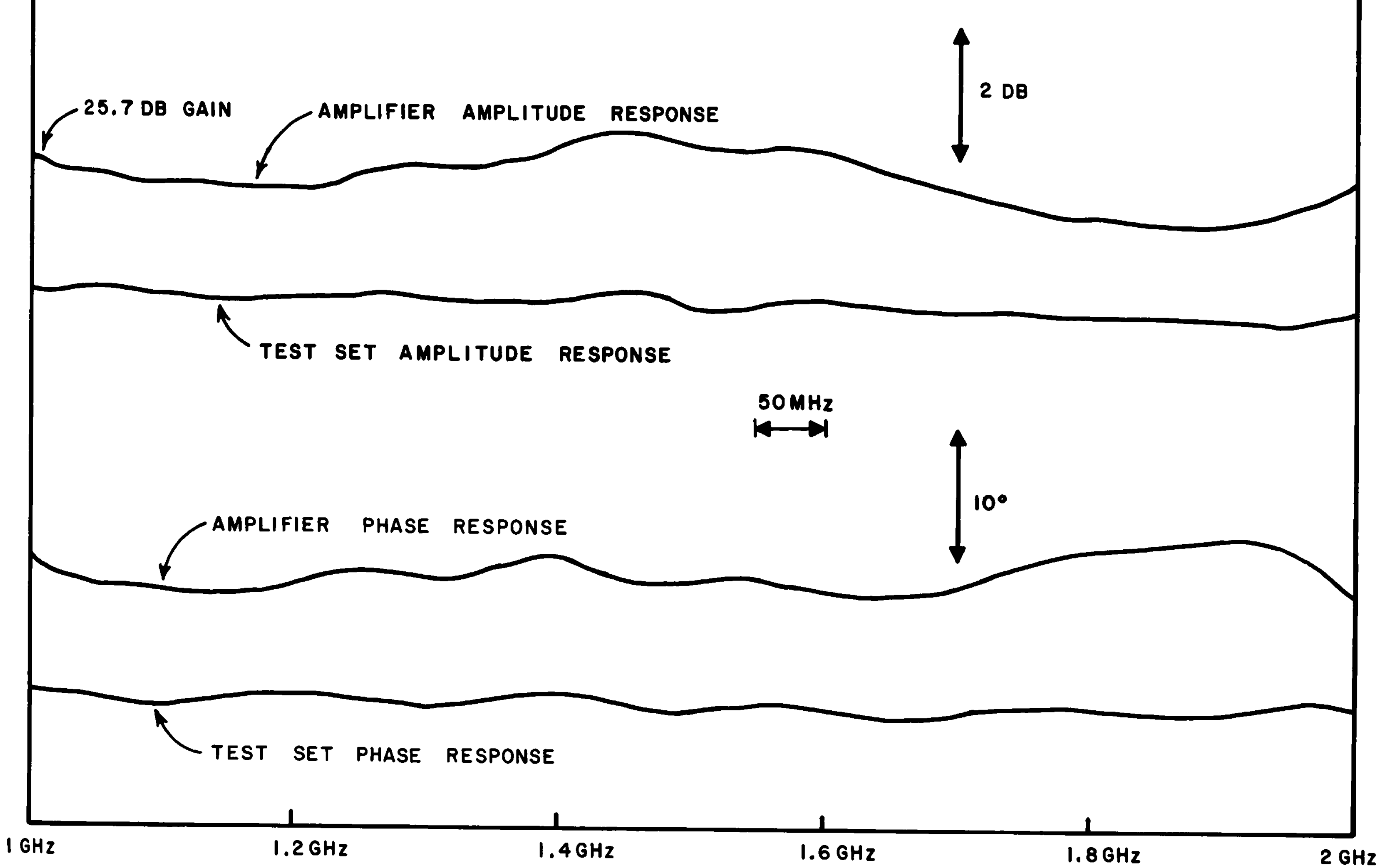


Figure 3 — Variation of propagation velocity (or delay time) of one manufacture of 1 5/8" coaxial cable. This variation changes the phase relationships between different frequency components in the IF signal and destroys the coherence of a pair of signals. However, the variation in the above cable is small enough to make the effect small and easily compensated. A second sample of identical manufacture gave the same variation to within 2 ppm.

Figure 4 — Amplitude and phase response of one manufacture of 1000-2000 MHz transistor amplifier. The important quantities are the amplitude variation and phase non-linearity in a 50 MHz band. Each repeater will consist of two transistor amplifiers and a cable equalizer.



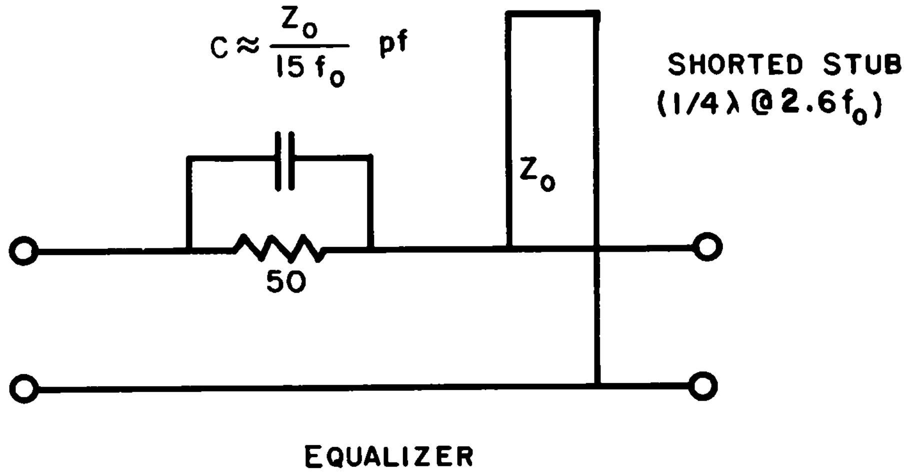


Figure 5 — Cable attenuation equalizer for an octave band starting at frequency f_0. The parameter, Z_0, is chosen for a particular length of cable that is being equalized. These equalizers have been constructed in strip-line and coaxial structures. Good results have been obtained with the coaxial structure. The equalizer is discussed in VLA Electronics Memorandum No. 7.

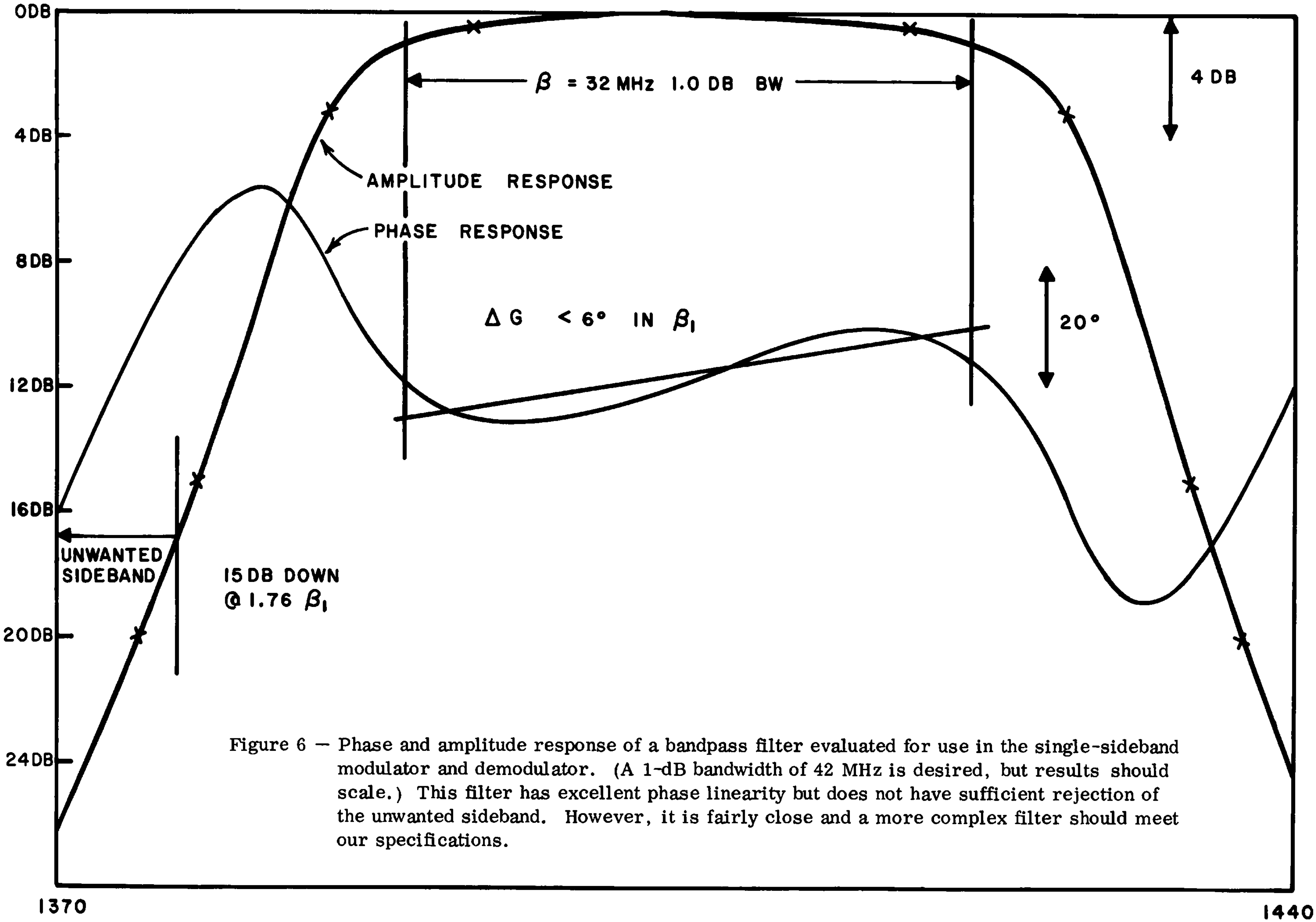


Figure 6 — Phase and amplitude response of a bandpass filter evaluated for use in the single-sideband modulator and demodulator. (A 1-dB bandwidth of 42 MHz is desired, but results should scale.) This filter has excellent phase linearity but does not have sufficient rejection of the unwanted sideband. However, it is fairly close and a more complex filter should meet our specifications.